DMIC

Review of Recent Developments

Metals Joining

D. C. Evans • March 13, 1968

ALUMINUM

Lockheed-Georgia investigators have recently reported on a study designed to determine the significance of welding variables and the factors necessary for the successful transfer of weld settings when inert-gas tungsten-arc welding aluminum alloys.(1) Welds were made in 1/4- and 3/4-inch 2219-T87 plate using a square-butt joint. The experiments were statistically designed, and the results were analyzed with the aid of a computer. The major variables influencing weld penetration were found to be travel speed, electrode position, current, electrode-tip diameter, and gas purity. Weld ultimate-strength variations were affected most by travel speed, electrode position, voltage, and gas purity. Variables accounting for variations in porosity were gas purity and the time-temperature function. The variables for which accurate instrumentation must be provided to transfer weld settings were (in order of importance) travel speed, electrode position, current, voltage, gas purity, and electrode-tip diameter. The investigation indicated that a change of the welding control system from one system to another may preclude the ability to successfully transfer a weld setting. For example, settings that are stable and satisfactory when welding with the conventional "automatic voltage" control system can be transferred to the "voltage-proximity-current" system, but the opposite is not always possible. However, duplicate trace recordings of the four dynamic variables (current, voltage, electrode position, and travel speed) indicate duplicate welds regardless of system change. The instrumentation should have high resolution and trace-type potentiometric recorders. An accumulation of variation in the minor static variables such as wire-deposit rate, gas flow, gas purity, etc., will cause significant variation in the resulting welds. Wire-deposit volume normally is not a critical variable; however, the angle and position of entry into the weld puddle is extremely sensitive. A change could invalidate electrode position and voltage data.

A final report on a 3-year program at Southwest Research covering the development of welding techniques and filler metals for high-strength aluminum alloys has been received by DMIC.(2) The report indicated that no new filler metals were found which gave properties any better than those that were commercially available. Intermetallic precipitates were shown to have a significant role in the initiation of fracture in 3/4-inch inert-gas tungsten-arc 2219-T87 alloy weldments. The natural aging characteristics of X7106-T63 alloy weldments made with X5180, 5356, and 5556 alloy filler wire were investigated. Marked increases in the uniaxial tensile strength of the weldments were observed to occur for aging periods of up to 8 weeks. In some cases, the strength of the weld deposit increased to a value such that the location of the fractures in tensile-test specimens shifted from the weld deposit to the heat-affected base metal.

Crack-susceptibility tests on 0.125-inch 2219-T87, 2014-T6, and X7106-T63 alloy sheet material established that, for this thickness, the susceptibility of X7106-T63 alloy to hot cracking during welding is comparable to that of 2014-T6 alloy. The 2219-T87 material exhibited a degree of crack susceptibility considerably lower than that of the other two alloys. Uniaxial tensile tests, hydraulic bulge tests, cylinder burst tests, MIT biaxial tests, and LTV biaxial tests were performed on 0.125-inch 2014-T6, 2219-T87, and X7106-63 parent metal and weldments. This study showed that the hydraulic bulge test may be used for the determination of the 1:1 biaxial mechanical properties of such weldments. These properties were also shown to be essentially equivalent to the uniaxial properties. Numerous graphs were presented to substantiate the conclusions drawn.

At Riso in Denmark, both pressure- and fusion-welding processes have been investigated for SAP-to-SAP joints.(3) The pressure-welding processes appear preferable from the standpoint of high-temperature strength. However, fusion welding, with careful control of heat input, was shown to be feasible.

Joint mechanical properties obtained by flash welding were considered to be indicative of any pressure-welding process. Flash-welded joints in SAP-930 exhibited satisfactory high-temperature strength. Ultimate tensile strengths were about 90 percent of parent-metal longitudinal strength but were considerably higher than parent-metal transverse strength. Elongation was relatively poor. These properties call for special design considerations, but the pressure-welding processes were concluded to be effective for joining SAP, although upsetting forces may cause complications in clamping.

Both inert-gas tungsten-arc and inert-gas metal-arc welding were investigated at Riso for end capping SAP tubes. A pure aluminum filler material was employed. To control heat input, a rotated arc was used for tungsten-arc welding and the short-circuiting process for metal-arc welding. Good joint strength and tightness at elevated temperature were obtained by both processes. However, in fusion with aluminum filler, particular attention was required to keep stresses low in the aluminum part of the joint because of aluminum's inferior high-temperature strength compared with that of SAP.

A stainless steel-aluminum transition joint for use at temperatures up to about 900 F has been developed at Atomics International.(4,5) The joint consists of a stainless steel tubular section bonded to a pure aluminum sleeve. A tungsten barrier layer is used to prevent diffusion between the joint components during hot isostatic pressure bonding. The stainless steel was plated with nickel. The bonding parameters were 10,000 psi at 1150 F for 15 minutes.

NICKEL AND SUPERALLOYS

Solar has evaluated several alloys for brazing foil-thickness (0.010 inch) TD Nickel, TD Nickel Chromium, L-605, and Inconel 625 in their program on the development of honeycomb-sandwich for use at 1800 F and above.(6,7) The selections were made on the basis of remelt temperature, high-temperature oxidation, and strength tests. Data on these alloys and the results of tensile tests on T joints are given in Tables 1, 2, 3, and 4. Engineers wishing to follow the Solar work on superalloy joining should be aware of a companion program under Contract Number F33615-67-C-1217 that has essentially the same objectives. The efforts are being carried on concurrently at Solar.

Hoppin, in a paper delivered recently at the ASM Metal Congress, emphasized that stress-rupture and creep strengths are the limiting factors when selecting brazing alloys for superalloys for high-temperature service.(8) Solar has the development of such data as one objective of its programs. Some of Hoppin's data are shown in Figures 1 and 2 for brazed lap joints in René 41. All of these joints had a 2t overlap and were aged at 1400 F for 16 hours.

A quotation from Hoppin's paper is pertinent to the reporting of any information on the brazing of high-temperature alloys.

> "Valid comparison of one filler metal to another may be made to aid in selection, but the apparent shear-strength results obtained from lap-joint testing really have no absolute value that can be translated into component design. Brazing-filler-metal selection ultimately must be made on the basis of component requirements and proven on actual or simulated components. There exists today a vast area of ignorance in applying brazed-joint test data intelligently. Far more work in the area of stress analysis is required to determine what tests are really needed to predict performance. In conjunction with this, available data is inadequate, often not reproducible, and many design engineers have avoided using brazed designs because of their recognition of this situation. The largest single factor holding back the greater use of brazing in superalloy fabrications is the lack of proper data and the knowledge of how to use it."

Two manuals on brazing of superalloys and other materials have become available. A Marshall Space Flight Center Manual provides information on materials, equipment, joint preparation, repair, and quality control for induction-brazed tubular

TABLE 1. BRAZE TEMPERATURES USED(6,7)

Superalloy	Braze Alloy	Braze Temperature, F	Superalloy	Braze Alloy	Braze Temperature, F
TD Nickel	TD-20	2375	L605	J8400	2170
TD Nickel	TD-6	2375	L605	J8100	2150
TD Nickel	J8600	2180	L605	CM52	2130
TD Nickel	60Pd-40Ni	2280	L605	J8600	2180
TD Nickel Chromium	TD-6	2380	Inconel 625	Palniro X	2200
TD Nickel Chromium	CM50	2090	Inconel 625	CM50	2070
TD Nickel Chromium	NX77	2200	Inconel 625	NX77	2170
TD Nickel Chromium	NSB	2350	Inconel 625	J8600	2180

TABLE 2. BRAZING ALLOYS SELECTED FOR EVALUATION(6,7)

Braze Alloy	Approximate Liquidus, F	Approximate Solidus, F	Nominal Chemical Compositions, wt% Ni	Cr	Pd	Si	B	Au	Mo	W	Fe	Co	Others
TD-6	—	—	Bal	16.0	—	4.0	—	—	17.0	5.0	—	—	—
TD-20	—	—	Bal	16.0	—	4.0	—	—	25.0	5.0	—	—	—
J8100	2080	1980	Bal	19.0	—	10.0	—	—	—	—	1.0	—	—
J8400	2100	2025	21.0	21.0	—	8.0	0.8	—	—	4.0	—	Bal	4C
J8600	2150	1800	Bal	33.0	25.0	4.0	—	—	—	—	—	—	—
CM50	1930	1905	Bal	—	—	3.5	1.9	—	—	—	—	—	—
CM52	1900	1800	Bal	—	—	4.5	2.9	—	—	—	1.4	—	—
NSB	—	—	Bal	—	—	2.0	0.8	—	—	—	—	—	—
60Pd-40Ni	2260	2260	40.0	—	60.0	—	—	—	—	—	—	—	—
NX77	2130	2020	Bal	5.0	—	7.0	1.0	—	—	1.0	X	4.0	—
Palniro X	—	—	X	X	X	—	—	X	—	—	—	—	—

TABLE 3. REMELT TEMPERATURE (6,7)

Superalloy	Braze Alloy	Remelt Temperature, F 1000 psi	Remelt Temperature, F 100 psi[a]
L605	J8400	2350[c]	--
T_{max} = 1800 F[b]	J8100	1860	2225
	CM52	2140	--
	J8600	2220	--
Inconel 625	Palniro X	2350[c]	--
T_{max} = 2000 F	CM50	2350[c]	--
	NX77	2350[c]	--
	J8600	2350[c]	--
TD Nickel	TD-20	2030	2420
T_{max} = 2000 F	TD-6	2055	2360
	J8600	2300	--
	60Pd-40Ni	1950	2320
TD Nickel Chromium	TD-6	2125	2450[c]
T_{max} = 2200 F	CM50	2025	2170
	NX77	2200	2240
	NSB	1950	2270

(a) Test only performed if the 1000 psi remelt temperature was <preliminary T_{max} + 150 F.
(b) T_{max} = the maximum temperature capability of alloy.
(c) At this temperature test terminated without failure.

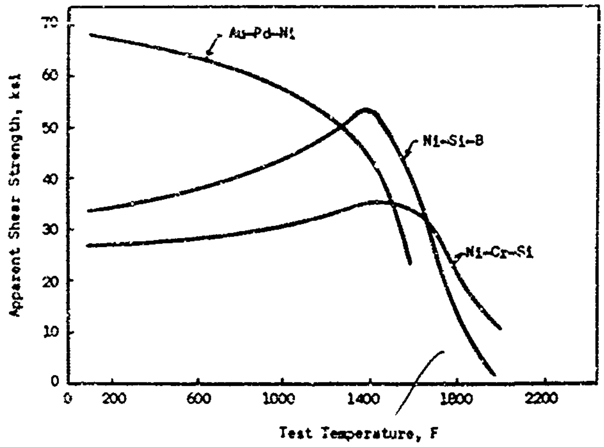

FIGURE 1. PROPERTIES OF BRAZED JOINTS IN RENÉ 41[8]

TABLE 4. TENSILE STRENGTH OF AS-BRAZED T-JOINTS AT ROOM TEMPERATURE AND AT T_{MAX} (6,7)

Superalloy	Braze Alloy	Test Temperature, F	Ultimate Tensile Strength, 1000 psi	Failure Mode[a]
L605	J8400	70	109.5	BA
L605	J8400	1800	21.5	PM
L605	J8100	70	74.7	BA
L605	J8100	1800	22.0	PM
L605	CM52	70	78.9	BA
L605	CM52	1800	20.1	PM
L605	J8600	70	132.0	BA
L605	J8600	1800	0.6	BA
Inconel 625	Palniro X	70	70.5	BA
Inconel 625	Palniro X	2000	3.2	BA
Inconel 625	CM50	70	106.5	BA
Inconel 625	CM50	2000	1.1	BA
Inconel 625	NX77	70	75.9	BA
Inconel 625	NX77	2000	10.5	PM
Inconel 625	J8600	70	109.0	PM
Inconel 625	J8600	2000	6.5	50% PM
TD Nickel	TD-20	70	67.8	PM
TD Nickel	TD-20	2000	17.4	PM
TD Nickel	TD-6	70	60.6	PM
TD Nickel	TD-6	2000	15.1	50% PM
TD Nickel	J8600	70	59.2	PM
TD Nickel	J8600	2000	5.0	BA
TD Nickel	60Pd-40Ni	70	65.1	PM
TD Nickel	60Pd-40Ni	2000	9.4	BA
TD Nickel Chromium	TD-6	70	111.6	30 to 100% PM
TD Nickel Chromium	TD-6	2200	2.3	BA
TD Nickel Chromium	CM50	70	103.7	BA
TD Nickel Chromium	CM50	2200	1.2	BA
TD Nickel Chromium	NX77	70	120.0	PM
TD Nickel Chromium	NX77	2200	0.6	BA
TD Nickel Chromium	NSB	70	111.0	BA
TD Nickel Chromium	NSB	2200	0.7	BA

(a) BA - braze alloy, PM - parent metal.

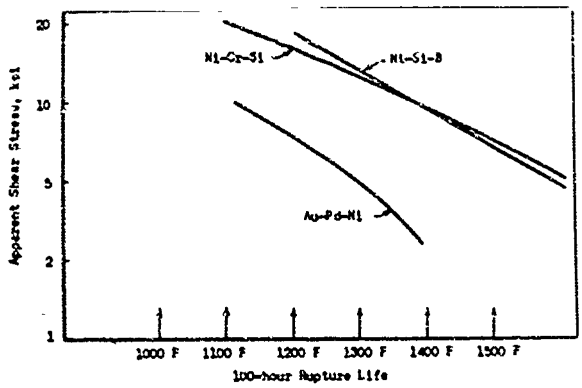

FIGURE 2. PROPERTIES OF BRAZED JOINTS IN RENÉ 41[8]

assemblies.[9] A Monsanto Research publication contains data on surface preparation, wetting and flow characteristics, mechanical properties, and base-metal reactions of 9 filler metals on 11 base metals.[10] It is designed to reduce the trials and errors for those developing new brazing applications. The base metals covered in the Monsanto manual are tantalum, Ta-10W, columbium, molybdenum, tungsten, Type 304 stainless steel, Haynes 25, Hastelloy C, Waspalloy, TD Nickel, and U-10Mo.

Inertia welding is receiving wide attention for the welding of the superalloys and also other metals of construction. General Electric is examining this process for the fabrication of jet-engine rotors.[11] The alloys included in the examination are Alloy 718, Udimet 700, and Ti-6Al-4V.

BERYLLIUM

North American Rockwell is continuing the development of beryllium-titanium composite structures.[12] Problems considered most important to the hinderance of complete success are ingot sheet quality, microcracking during forming and resistance brazing, and warpage during electron-beam brazing. The warpage during electron-beam brazing was considered insurmountable. Resistance spot diffusion brazing appears to be the most feasible method of fabricating the composite truss-core panels desired.

Solar engineers in a program to develop brazing alloys which flow well (capillary flow) on beryllium have been looking mainly at the effect of compositional changes on silver- and titanium-base alloys.[13] Ternary and quarternary silver-base alloys based on the silver-copper eutectic are being evaluated for wetting, flow, melting characteristics, and base-metal reactions. Six alloys have been found that show promise. The titanium-base-alloy studies follow those used on the silver-base systems and involve the alteration of known alloys plus additions to a Ti-5.6Be alloy. Aluminum alloys are also under study as possible brazing alloys for beryllium.

In another program at Solar, methods are under study for the development of beryllium honeycomb-sandwich structures.[14] To date, much of the effort has been expended on the methods of fabrication for the sandwich parts. Brazing and diffusion bonding are the joining methods under investigation. The brazing alloys covered in the capillary-flow work described above are being evaluated in this study. The alloy 63Ag-27Cu-10Sn has been tentatively chosen as the most promising for making the sandwich.

Several additional references to recent beryllium-joining developments are covered in the DMIC Review of Recent Developments on Beryllium, January 26, 1968. Included in this review is a summarization of Battelle/Columbus work on electron-beam welding of 1/16- and 1/8-inch-thick S-200-C beryllium.[15]

NEW PROGRAMS

Diffusion Bonding

(a) Contract AF 33(615)-66-03515, Manufacturing Process Development to Produce Large Structural Titanium Components by Diffusion Bonding Laminated Sections, North American-Rockwell, Inc., September 8, 1967.

(b) Contract F33(615)-67-C-1738, Nondestructive Testing Techniques for Diffusion Bonded Laminates, North American-Rockwell, Inc., June 13, 1967.

(c) Contract F33615-67-C-1802, Fabrication Techniques for Advanced Composite Attachments and Joints, North American-Rockwell, Inc., June 14, 1967.

Resistance Welding

(a) Contract F33615-68-C-1289, High Frequency Resistance Welding Titanium Tee Shapes, Columbus Laboratories, Battelle Memorial Institute, January 9, 1968.

REFERENCES

(1) Gillespie, P. A., "A Study of Inert-Gas Welding Process Transferability of Set-Up Parameters", Final Report NASA CR-83948, Lockheed-Georgia Division, Lockheed Aircraft Corporation, Marietta, Ga., Contract NAS8-11435 (January 1, 1967).

(2) Burghard, H. C., Jr., and Norris, E. B., "Development of Welding Techniques and Filler Metals for High-Strength Aluminum Alloys", Final Report NASA CR-77511, Southwest Research Institute, San Antonio, Tex., Contracts NAS 8-1529, and NAS 8-20160 (May 27, 1966).

(3) Aastrup, P., Mol, A., and Knudsen, P., "Joining Methods Applied to Sintered Aluminum Products", Riso Report 145, Danish Central Welding Institute, Copenhagen and The Danish Atomic Energy Commission, Denmark (October 1966).

(4) Jackson, W. J., "Development of Stainless Steel-Aluminum Transition Joint for High-Temperature Service", AEC Report AI-CE-72, Atomics International Division, North American-Rockwell, Inc., Los Angeles, Calif., Contract AT(38-1)-430 (September 25, 1967).

(5) Supan, E. C., "Investigation of Tungsten as a Diffusion Barrier for HWOCR SAP-Steel Pressure Tube Transition Joints", Report AI-CE-66, Atomics International Division, North American-Rockwell, Inc., Canoga Park, Calif., Contract AT(38-1)-430 (September 15, 1967).

(6) Preliminary information reported by Solar Division, International Harvester Company, San Diego, Calif., under U. S. Air Force Contract F33615-67-C-1211.

(7) Preliminary information reported by Solar Division, International Harvester Company, San Diego, Calif., under U. S. Air Force Contract F33615-67-C-1211.

(8) Hoppin, G. S., III, "Critical Properties of Superalloy Brazed Joints", Report TM 67-701, General Electric Company, Cincinnati, O. (November 8, 1967).

(9) Induction Brazing Manual, Technical Report, George C. Marshall Space Flight Center (NASA), Huntsville, Ala.

(10) Robbins, W. P., "Brazing Superalloys and Refractory Metals", Report MLM-1322, Mound Laboratory, Monsanto Research Corporation, Miamisburg, O., Contract AT-33-1-GEN-53 (March 10, 1967).

(11) Preliminary information reported by the Flight Propulsion Division, General Electric Company, Cincinnati, O., under U. S. Air Force Contract F33615-67-C-1864.

(12) "Fabricating a Beryllium and Beryllium-Titanium Composite Panel", Final Report D2-109002-1, Volume II, The Boeing Company, Seattle, Wash., Contract NAS 8-20534 (October 12, 1967).

(13) Preliminary information reported by Solar Division, International Harvester Company, San Diego, Calif., under U. S. Air Force Contract AF 33(615)-2853.

(14) Preliminary information reported by Solar Division, International Harvester Company, San Diego, Calif., under NASA Contract NAS 8-21215.

(15) Hauser, D., and Monroe, R. E., "Electron-Beam Welding of Beryllium-II", Final Report AFML-TR-66-215, Part II, Columbus Laboratories, Battelle Memorial Institute, Columbus, O., Contract AF 33(615)-2671 (October 1967).

DMIC Reviews of Recent Developments present brief summaries of information which has become available to DMIC in the preceding period (usually 3 months), in each of several categories. DMIC does not intend that these reviews be made a part of the permanent technical literature. Copies of referenced reports are not available from DMIC; most can be obtained from the Defense Documentation Center, Cameron Station, Alexandria, Virginia 22314.

R. W. Endebrock, Editor